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(54) **APPARATUS AND METHOD FOR SYNCHRONIZING DYNAMIC PROCESS DATA ACROSS REDUNDANT INPUT/OUTPUT MODULES**

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(58) **Field of Classification Search**
None
See application file for complete search history.

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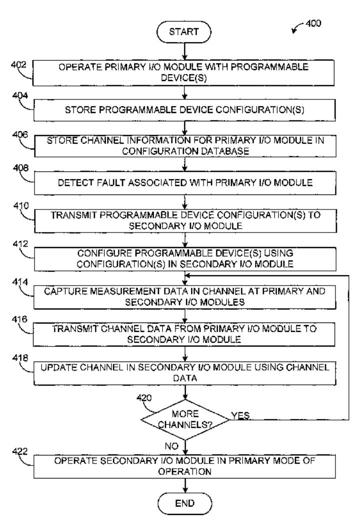
(57) **ABSTRACT**

A method includes receiving first data at a first I/O module from a second I/O module, where the first data defines a programmable device configuration. The method also includes configuring a programmable device in the first I/O module based on the first data, where the programmable device is associated with a first I/O channel of the first I/O module. The method further includes receiving second data at the first I/O module from the second I/O module, where the second data is associated with a second I/O channel of the second I/O module. In addition, the method includes synchronizing the first I/O channel with the second I/O channel based on the second data.

20 Claims, 3 Drawing Sheets



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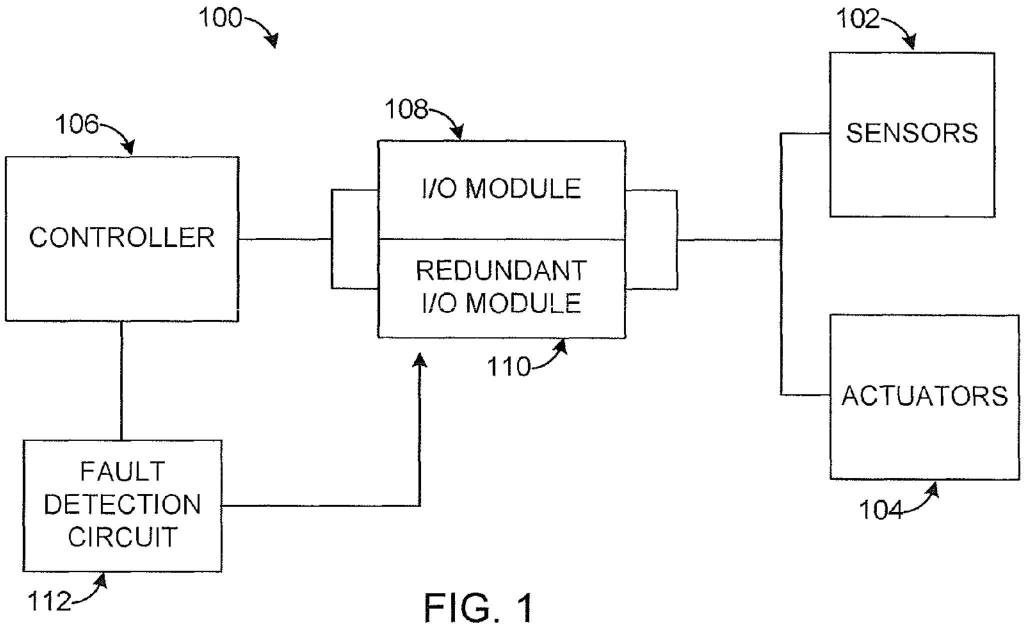
100
106
CONTROLLER
108
I/O MODULE
REDUNDANT I/O MODULE
110
102
SENSORS
ACTUATORS
104
FAULT DETECTION CIRCUIT
112

FIG. 1

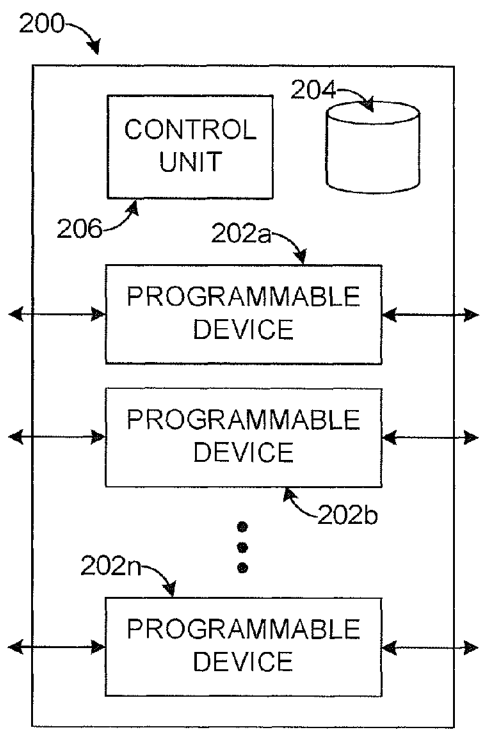
200
CONTROL UNIT
204
206
202a
PROGRAMMABLE DEVICE
PROGRAMMABLE DEVICE
202b
202n
PROGRAMMABLE DEVICE

FIG. 2

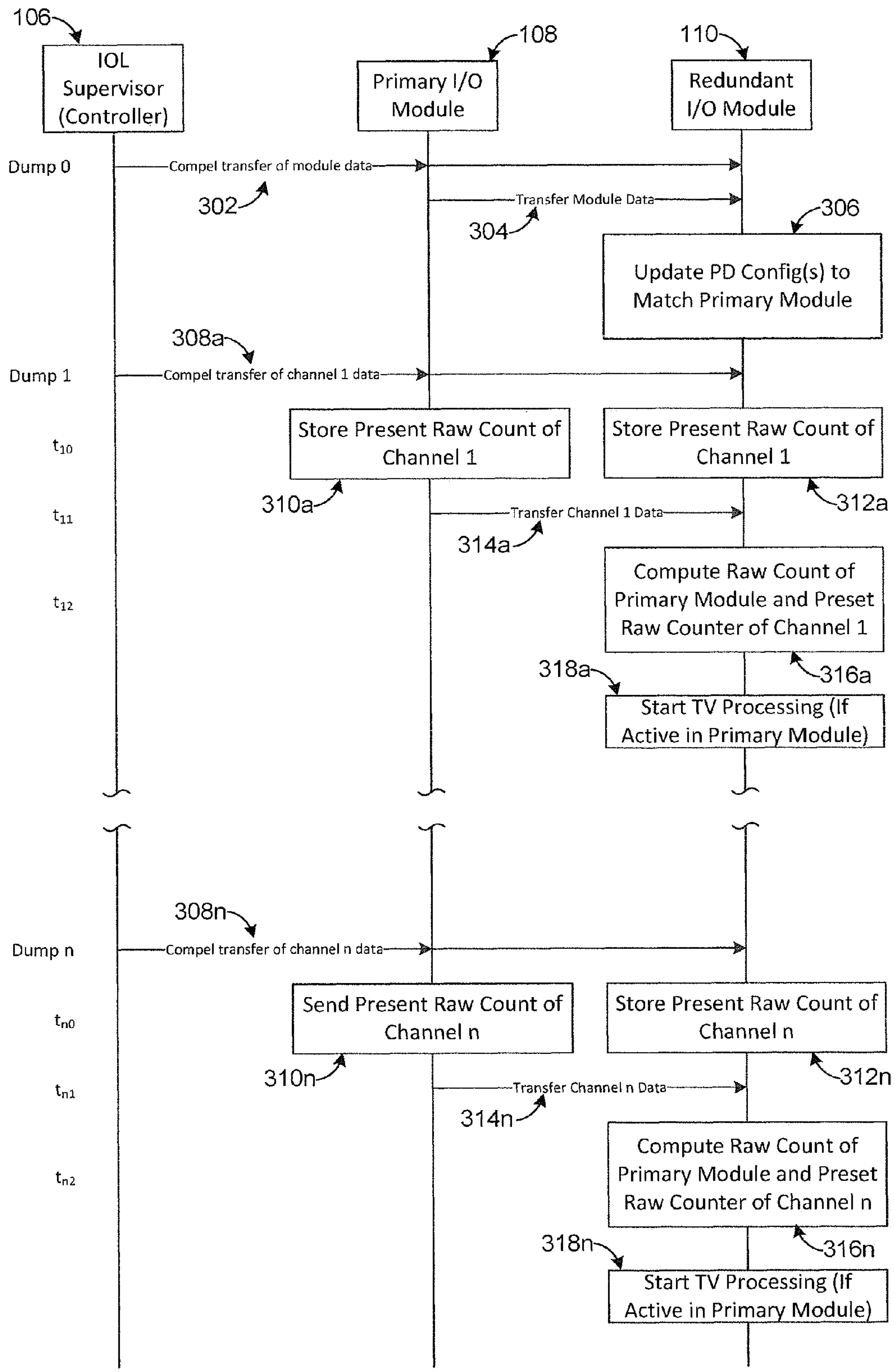
106
IOL Supervisor (Controller)
108
Primary I/O Module
110
Redundant I/O Module
Dump 0
Compel transfer of module data
302
Transfer Module Data
304
306
Update PD Config(s) to Match Primary Module
308a
Dump 1
Compel transfer of channel 1 data
t_{10}
Store Present Raw Count of Channel 1
Store Present Raw Count of Channel 1
310a
312a
t_{11}
Transfer Channel 1 Data
314a
t_{12}
Compute Raw Count of Primary Module and Preset Raw Counter of Channel 1
318a
316a
Start TV Processing (If Active in Primary Module)
308n
Dump n
Compel transfer of channel n data
t_{n0}
Send Present Raw Count of Channel n
Store Present Raw Count of Channel n
310n
312n
t_{n1}
Transfer Channel n Data
314n
t_{n2}
Compute Raw Count of Primary Module and Preset Raw Counter of Channel n
318n
316n
Start TV Processing (If Active in Primary Module)

FIG. 3

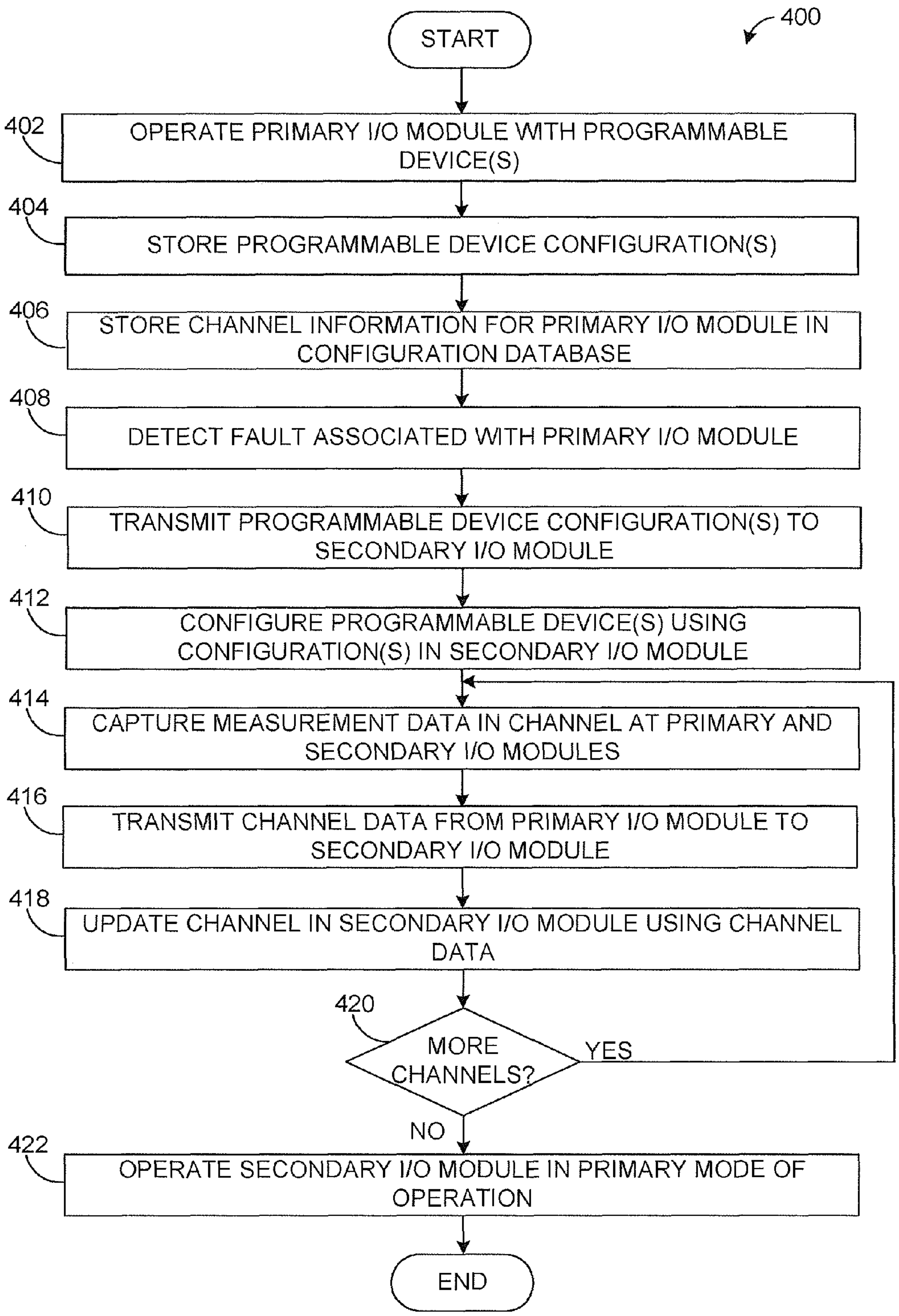
400
START
402
OPERATE PRIMARY I/O MODULE WITH PROGRAMMABLE DEVICE(S)
404
STORE PROGRAMMABLE DEVICE CONFIGURATION(S)
406
STORE CHANNEL INFORMATION FOR PRIMARY I/O MODULE IN CONFIGURATION DATABASE
408
DETECT FAULT ASSOCIATED WITH PRIMARY I/O MODULE
410
TRANSMIT PROGRAMMABLE DEVICE CONFIGURATION(S) TO SECONDARY I/O MODULE
412
CONFIGURE PROGRAMMABLE DEVICE(S) USING CONFIGURATION(S) IN SECONDARY I/O MODULE
414
CAPTURE MEASUREMENT DATA IN CHANNEL AT PRIMARY AND SECONDARY I/O MODULES
416
TRANSMIT CHANNEL DATA FROM PRIMARY I/O MODULE TO SECONDARY I/O MODULE
418
UPDATE CHANNEL IN SECONDARY I/O MODULE USING CHANNEL DATA
420
MORE CHANNELS?
YES
NO
422
OPERATE SECONDARY I/O MODULE IN PRIMARY MODE OF OPERATION
END

FIG. 4

APPARATUS AND METHOD FOR SYNCHRONIZING DYNAMIC PROCESS DATA ACROSS REDUNDANT INPUT/OUTPUT MODULES

TECHNICAL FIELD

This disclosure relates generally to synchronization systems. More specifically, this disclosure relates to an apparatus and method for synchronizing dynamic process data across redundant input/output (I/O) modules.

BACKGROUND

Controllers are widely used in process control applications. A controller is typically configured to receive process measurements from one or more sensors and generate control signals for one or more actuators. The controller typically adjusts the one or more actuators in order to keep one or more process variables at or near desired setpoint value(s). Input/output (I/O) modules are often used to transport data to and from controllers or other devices in process control applications. The I/O modules are normally used to process the data in some way, such as by performing analog-to-digital or digital-to-analog conversion.

SUMMARY

This disclosure provides an apparatus and method for synchronizing dynamic process data across redundant input/output (I/O) modules.

In a first embodiment, a method includes receiving first data at a first I/O module from a second I/O module, where the first data defines a programmable device configuration. The method also includes configuring a programmable device in the first I/O module based on the first data, where the programmable device is associated with a first I/O channel of the first I/O module. The method further includes receiving second data at the first I/O module from the second I/O module, where the second data is associated with a second I/O channel of the second I/O module. In addition, the method includes synchronizing the first I/O channel with the second I/O channel based on the second data.

In a second embodiment, an apparatus includes a first I/O module, which includes a programmable device associated with a first I/O channel and a control unit. The control unit is configured to receive first data from a second I/O module, where the first data defines a programmable device configuration. The control unit is also configured to configure the programmable device based on the first data. The control unit is further configured to receive second data from the second I/O module, where the second data is associated with a second I/O channel of the second I/O module. In addition, the control unit is configured to synchronize the first I/O channel with the second I/O channel based on the second data.

In a third embodiment, a method includes storing first data defining a configuration of a programmable device in a first input/output (I/O) module, where the programmable device is associated with a first I/O channel. The method also includes storing second data associated with the first I/O channel. The method further includes, during a synchronization process, transmitting the first and second data to a second I/O module.

Other technical features may be readily apparent to one skilled in the art from the following figures, descriptions, and claims.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of this disclosure, reference is now made to the following description, taken in conjunction with the accompanying drawings, in which:

FIG. **1** illustrates a portion of an example process control system supporting synchronization of dynamic process data across redundant input/output (I/O) modules according to this disclosure;

FIG. **2** illustrates an example I/O module supporting synchronization of dynamic process data according to this disclosure;

FIG. **3** illustrates an example synchronization of dynamic process data across redundant I/O modules according to this disclosure; and

FIG. **4** illustrates an example method for synchronizing dynamic process data across redundant I/O modules according to this disclosure.

DETAILED DESCRIPTION

FIGS. **1** through **4**, discussed below, and the various embodiments used to describe the principles of the present invention in this patent document are by way of illustration only and should not be construed in any way to limit the scope of the invention. Those skilled in the art will understand that the principles of the invention may be implemented in any type of suitably arranged device or system.

FIG. **1** illustrates a portion of an example process control system **100** supporting synchronization of dynamic process data across redundant input/output (I/O) modules according to this disclosure. As shown in FIG. **1**, the system **100** includes one or more sensors **102**, one or more actuators **104**, and one or more controllers **106**. Each sensor **102** measures at least one characteristic of a process system. For example, a sensor **102** could measure temperature, pressure, flow rate, material composition, vibration, or any other or additional characteristic(s). Each sensor **102** includes any suitable structure for measuring one or more characteristics associated with a process system. A process system represents any system or portion thereof configured to process one or more materials in some manner.

Each actuator **104** performs one or more actions to modify at least one characteristic of a process system. For example, an actuator **104** could adjust the operation of a valve, motor, pump, or other industrial equipment within the process system. Each actuator **104** includes any suitable structure for modifying one or more characteristics associated with a process system.

Each controller **106** receives data from one or more sensor(s) **102** and uses the data to control one or more actuator(s) **104**. For example, a controller **106** could use the sensor measurements and a model representing the expected behavior of a process variable. The controller **106** could then generate a control signal for an actuator that affects the process variable. Ideally, the controller **106** can do this in order to keep one or more process variables at or near one or more desired setpoint values. Each controller **106** includes any suitable structure for controlling industrial equipment, such as a controller that implements model predictive control (MPC) or other control technology.

The system **100** also includes at least one I/O module **108** and at least one redundant I/O module **110**. Each I/O module **108** represents a primary I/O module used to pass data between the controller(s) **106** and the sensor(s) **102**/actuator(s) **104**. Each redundant I/O module **110** represents a secondary or backup I/O module that can used to pass data between the controller(s) **106** and the sensor(s) **102**/actuator(s) **104** if and when the primary I/O module **108** fails. Each I/O module **108-110** can further provide various processing functions, such as analog-to-digital conversion, digital-to-analog conversion, or pulse counting. Each I/O module **108-110** includes any suitable structure configured to receive signals from a source and to provide signals to a destination (possibly after converting the signals to a different form).

Note that any number of I/O modules **108** and any number of redundant I/O modules **110** could be used in the system **100**, and those numbers may or may not be equal. For example, there could be a 1:1 mapping where each I/O module **108** has an associated redundant I/O module **110**. There could also be a mapping where only some of the I/O modules **108** have associated redundant I/O modules **110**. As a particular example, only the I/O modules **108** associated with critical control data could have associated redundant I/O modules **110**.

Also note that while the I/O module **108** and the redundant I/O module **110** are shown as separate elements in FIG. **1**, an I/O module could function in different roles or modes at different times. For example, an I/O module could function in the primary role (I/O module **108**) during some time periods and in the redundant role (I/O module **110**) during other time times. The use of separate modules **108-110** in FIG. **1** is merely meant to illustrate the use of primary and redundant I/O elements.

In particular embodiments, the controller **106** and the I/O modules **108-110** are arranged in a bidirectional multi-drop network using a master-slave protocol. The controller **106** can function as a communication master device, and the I/O modules **108-110** can function as communication slave devices.

A fault detection circuit **112** is used to detect a fault condition in an I/O module **108** and trigger a switchover to the associated redundant I/O module **110**. For example, a fault may occur in an I/O module **108**, such as due to a power failure, a hardware failure, or a software/firmware fault. The fault condition may be detected by the fault detection circuit **112**, which can signal the controller **106**. The controller **106** can then cause the associated redundant I/O module **110** to assume primary operation. Alternatively, the fault detection circuit **112** could cause the reconfiguration of the I/O modules. In this way, the failure of an I/O module **108** can be quickly remedied, reducing or minimizing disruptions to the process control operation. The fault detection circuit **112** includes any suitable structure for identifying a fault with at least one I/O module.

In order to support the use of a redundant I/O module **110**, the primary and redundant I/O modules **108-110** are synchronized. This allows the redundant I/O module **110** to take over operation substantially immediately upon a failure of the primary I/O module **108**. In conventional systems, I/O modules include discrete circuitry that handles input or output signals in one or more channels, where the discrete circuitry in a secondary I/O module matches the discrete circuitry in a primary I/O module. Because the circuitry was designed to be the same, the conventional I/O modules could be synchronized simply by synchronizing the configuration databases of the conventional I/O modules. A configuration database defines the setup and operation of one or more I/O channels. By synchronizing the configuration databases of the primary and redundant I/O modules, the redundant I/O module could easily take over operation for a primary I/O module.

Newer I/O modules include programmable devices, such as field programmable gate arrays. Each programmable device performs the input and output signal processing operations for an I/O channel. These I/O modules need not have discrete circuitry for each channel. Instead, the programmable device for each channel is reconfigurable into a number of different configurations. This creates difficulty in synchronizing primary and redundant I/O modules.

In accordance with this disclosure, during the synchronization process, a programmable device in a redundant I/O module **110** is configured to match the configuration of an associated programmable device in a primary I/O module **108**. This is done in addition to synchronizing the configuration databases of the I/O modules **108-110**. For example, the programmable devices in the redundant I/O module **110** can be reconfigured before each I/O channel's data in the primary I/O module's configuration database is sent from the primary I/O module **108** to the redundant I/O module **110**. This can help to ensure that each I/O channel's hardware in the redundant I/O module **110** is configured properly before that I/O channel's data is synchronized with the corresponding channel in the primary I/O module **108**. In this way, the redundant I/O module **110** can be rapidly reconfigured and synchronized in order to take over operation of the primary I/O module **108**.

Moreover, when conventional I/O modules are used in a redundant configuration, the I/O modules typically calculate the same process variable value independently and provide substantially the same value for use by a controller. For example, if two conventional I/O modules receive the same analog input signal and perform analog-to-digital conversion, the outputs of the two I/O modules would typically be substantially equal (assuming each module is operating properly). As a result, switching from one I/O module to the other could be done without causing severe process interruptions since a controller or actuator would not see a large change in its input.

This may not be the case with newer I/O modules. For example, some newer I/O modules operate by receiving an analog or digital input signal and counting the number of pulses in the input signal using a counter. Situations can therefore easily arise where the number of pulses counted by a primary I/O module differs from the number of pulses counted by a redundant I/O module. This most often occurs when I/O module **110** is powered after I/O module **108** has been loaded with its configuration and started operation. In this case, the counter output in the redundant I/O module **110** is almost guaranteed to be different than the counter output in the primary I/O module **108**.

In accordance with this disclosure, one or more measurement values from a primary I/O module **108** are transferred to a redundant I/O module **110** as part of the synchronization process. The measurement values from the primary I/O module **108** are used to update the I/O channel(s) in the redundant I/O module **110**. For example, a difference between counter values in the primary and redundant I/O modules **108-110** could be identified and used to update the counter in the redundant I/O module **110**. Once again, this can help to facilitate a switchover from primary to backup I/O modules with little or no interruption in the control of an industrial process.

Additional details about synchronizing I/O modules are provided below. The synchronization technique described here could be used to support any number of redundant I/O modules **110** in any suitable system.

Although FIG. **1** illustrates a portion of one example process control system **100** supporting synchronization of dynamic process data across redundant I/O modules, various changes may be made to FIG. **1**. For example, the system **100** could include any number of sensors, actuators, controllers, primary and redundant I/O modules, and fault detection circuits. Also, the functional division shown in FIG. **1** is for illustration only. Various components in FIG. **1** could be combined, subdivided, or omitted and additional components could be added according to particular needs. For instance, the fault detection circuit **112** may be incorporated into one or more of the I/O modules **108**-**110** or in the controller **106**. Further, while shown as coupling both sensors and actuators to a controller, an I/O module could couple only sensors to a controller or be used in any other suitable manner. In addition, the primary and redundant I/O modules are not limited to use with sensors, actuators, and controllers. The synchronization technique described in this document could be used with primary and redundant I/O modules that support communications between any suitable source(s) and destination(s).

FIG. **2** illustrates an example I/O module **200** supporting synchronization of dynamic process data according to this disclosure. The I/O module **200** could, for instance, represent an example implementation of the I/O module(s) **108** or the redundant I/O module(s) **110** in FIG. **1**. Note, however, that the I/O module **200** could be used in any other suitable system.

As shown in FIG. **2**, the I/O module **200** includes one or more programmable devices **202***a*-**202***n*. As noted above, each programmable device **202***a*-**202***n* performs the input and output signal processing operations for an I/O channel. For example, a programmable device **202***a*-**202***n* could receive a digital or analog input signal, count a number of pulses in the input signal using a counter, and output a digital value identifying the counted number of pulses. A programmable device **202***a*-**202***n* could also perform any other suitable operations. Each programmable device **202***a*-**202***n* includes any suitable programmable structure supporting signal processing operations. Each programmable device **202***a*-**202***n* could, for instance, represent a field programmable gate array (FPGA), complex programmable logic device (CPLD), digital signal processor, or Flash memory or other non-volatile memory device.

The I/O module **200** could include a single programmable device **202***a* to support a single I/O channel. The I/O module **200** could also include multiple programmable devices **202***a*-**202***n* to support multiple I/O channels. Each I/O channel could be used to pass data between any suitable devices or systems.

The I/O module **200** also includes a memory **204** and a control unit **206**. The memory **204** can be used to store various information associated with the I/O module **200**. For example, the memory **204** could store the configuration database for the I/O module **200**, where the configuration database defines the setup and operation of the I/O channel(s). The memory **204** could also store data defining the configuration of each programmable device **202***a*-**202***n* and any measurement data (such as counter values) associated with each programmable device **202***a*-**202***n*. The memory **204** includes any suitable storage and retrieval device(s).

The control unit **206** uses this information to support redundancy operations involving the I/O module **200**. For example, if the I/O module **200** is operating in the primary mode (as an I/O module **108**), the control unit **206** can collect information for the configuration database, the programmable device configuration(s), and the measurement value(s) and store that information in the memory **204**. The control unit **206** can also transmit that information to a redundant I/O module **110** when necessary.

If the I/O module **200** is operating in the redundant mode (as an I/O module **110**), the control unit **206** can receive information for the configuration database, the programmable device configuration(s), and the measurement value(s) from a primary I/O module **108**. The control unit **206** uses the programmable device configuration(s) to reconfigure the programmable device(s) **202***a*-**202***n*. The control unit **206** also uses the configuration database to configure the I/O channel (s) properly. The control unit **206** further uses the measurement value(s) to update the programmable device(s) **202***a*-**202***n* to be substantially synchronized with the operation of the primary I/O module **108**.

The control unit **206** includes any suitable structure for controlling operation of an I/O module. The control unit **206** could, for example, represent a microprocessor, microcontroller, digital signal processor, FPGA, application specific integrated circuit (ASIC), or other processing or computing device.

Although FIG. **2** illustrates one example of an I/O module **200** supporting synchronization of dynamic process data, various changes may be made to FIG. **2**. For example, the I/O module **200** could include any number of programmable devices in any suitable configuration to support any number of I/O channels. Also, the functional division shown in FIG. **2** is for illustration only. Various components in FIG. **2** could be combined, subdivided, or omitted and additional components could be added according to particular needs.

FIG. **3** illustrates an example synchronization of dynamic process data across redundant I/O modules according to this disclosure. In this example, the synchronization is controlled by an I/O link (IOL) supervisor, which in this case can be a controller **106** of FIG. **1**. The I/O modules being synchronized are a primary I/O module **108** and a redundant I/O module **110** in FIG. **1**. Note, however, that the synchronization technique could be used in any other suitable system.

In some embodiments, the synchronization technique generally occurs as follows. First, one or more programmable devices **202***a*-**202***n* of the redundant I/O module **110** are reconfigured using data from the primary I/O module **108**. The configuration(s) of the programmable device(s) **202***a*-**202***n* can be stored in the primary I/O module's database (sometimes referred to as the "slot 0" database). Each programmable device (each I/O channel) could have its own record in the database. These database records can be the first sent to the redundant I/O module **110** during the synchronization process. Once received from the primary I/O module **108**, the programmable device(s) **202***a*-**202***n* in the redundant I/O module **110** can be configured based on the received database record(s). The reconfiguration of the programmable device(s) **202***a*-**202***n* can occur first since the I/O channel data to be transferred next may rely on the programmable device (s) **202***a*-**202***n* being properly configured. Once the one or more programmable devices **202***a*-**202***n* are properly configured, each individual I/O channel can be synchronized.

The transfer of the initial programmable device configuration(s) and the subsequent transfer(s) of I/O channel information may be referred to as data "dumps." Also, each device involved in the synchronization process could transmit data by placing the data into an IOL transmit buffer for transmission, and each device could process data received in its IOL receive buffer.

As shown in FIG. **3**, the synchronization technique begins with an initial data dump ("Dump 0"), where the controller **106** sends a message **302** compelling the transfer of "module data" to the primary and redundant I/O modules **108**-**110**. The module data represents the database record(s) identifying the configuration(s) of the programmable device(s) **202***a*-**202***n* in the primary I/O module **108**. The message **302** is received by both I/O modules **108**-**110**, allowing the primary I/O module **108** to prepare to send the data and the redundant I/O module **110** to prepare to receive the data.

The primary I/O module **108** sends the module data to the redundant I/O module **110** in one or more messages **304**. Each message **304** could include one or multiple database records. The redundant I/O module **110** uses the module data during operation **306** to configure the programmable device(s) **202***a*-**202***n* in the redundant I/O module **110**. At the end of the operations **306**, the programmable device(s) **202***a*-**202***n* in the redundant I/O module **110** can have the same operational configuration as the programmable device(s) **202***a*-**202***n* in the primary I/O module **108**.

The synchronization technique then transfers each I/O channel's data to the redundant I/O module **108**, where each I/O channel's data is sent in a separate dump operation ("Dump 1" through "Dump n"). For the first I/O channel, the controller **106** sends a message **308***a* compelling the transfer of "channel 1" data to the primary and redundant I/O modules **108**-**110**. In response, the primary I/O module **108** stores its measurement data for the first I/O channel during operation **310***a*, and the redundant I/O module **110** stores its measurement data for the first I/O channel during operation **312***a*. These values can be sampled at substantially the same time. In this example, this includes each I/O module **108**-**110** storing its counter value, although other measurement data could be used.

The primary I/O module **108** then sends the "channel 1" data to the redundant I/O module **110** in one or more messages **314***a*. The redundant I/O module **110** can retrieve the data and calculate an offset during operation **316***a*. The offset can be calculated as the difference between the value stored by the primary I/O module **108** in operation **310***a* and the value stored by the redundant I/O module **110** in operation **312***a*. The offset could be used in any suitable manner, such as by adding the offset value to the counter in the redundant I/O module **110** or storing the offset value for later use. Note, however, that the offset or the value from the primary I/O module **108** could be used in any suitable manner.

At this point, the first I/O channel in the redundant I/O module **110** is ready for use, and target value (TV) processing can commerce during operation **318***a* (assuming that the primary I/O module **108** had been performed TV processing prior to the switchover). Target value processing can involve a user setting a target value that is compared against the accumulated counter value, which represents the input pulse count. When the accumulated value reaches or exceeds the target value, some action can be taken, such as toggling an output value and resetting the counter.

The same process could be repeated for all remaining I/O channels. In FIG. **3**, for example, operations **308***n*-**318***n* are repeated for "channel n." At the end of this procedure, all n I/O channels of the redundant I/O module **110** have been synchronized with the I/O channels of the primary I/O module **108**. Note that the number of dumps shown in FIG. **3** is for illustration only and that fewer data dumps or channels, perhaps even a single data dump or channel, may be synchronized.

As can be seen in FIG. **3**, times t_{x0}, t_{x1}, and t_{x2} are shown for each I/O channel dump (where x denotes the I/O channel number). In this example embodiment, the recording of the counter value for each I/O channel dump occurs at time t_{x0}. In particular embodiments, the time t_{x0} denotes the time of a "gap has occurred" event. Depending on the implementation, the "gap has occurred" event can be represented by a hardware signal that indicates there is no traffic on an I/O link. It is conventionally used by firmware to know when a message is complete. Because it is generated digitally, the "gap has occurred" event can be detected at essentially the same time at each I/O module on the I/O link. Any skew between when the "gap has occurred" event is detected in different I/O modules could be very small, such as due to (i) a difference in propagation times of different transceivers and (ii) a difference in clock frequencies in different devices. The small skew allows the counter outputs in the different I/O modules **108**-**110** to be sampled at essentially the same time, which allows an accurate offset between the counters to be determined. The channel data for each I/O channel dump is transmitted from the primary I/O module **108** starting at time t_{x1}, and the reception of the channel data for each I/O channel dump is completed at the redundant I/O module **110** at time t_{x2}.

As can be seen here, the synchronization technique can have various benefits depending on the implementation. For example, the use of the "gap has occurred" event for sampling counter values can reduce or eliminate the need for special synchronization mechanisms in the I/O modules. Also, very little burden is placed on the controller **106** or the programmable devices **202***a*-**202***n* to support this functionality. Further, no special inter-module signaling is required, just the communication of data messages through conventional IOL transmit and receive buffers. Finally, the I/O modules **108**-**110** may not require a large amount of programming code to implement the failover functionality.

Although FIG. **3** illustrates one example of the synchronization of dynamic process data across redundant I/O modules, various changes may be made to FIG. **3**. For example, the "gap has occurred" event represents one of various ways in which the sampling of counter values or other measurement values can be synchronized in different I/O modules. Also, as noted above, counter values are one of various types of measurement data that could be synchronized across multiple I/O modules. Moreover, the synchronization of measurement data need not occur at all if the redundant I/O module **110** already has substantially the same data (such as when both I/O modules perform analog-to-digital or digital-to-analog conversion of the same input signal).

FIG. **4** illustrates an example method **400** for synchronizing dynamic process data across redundant I/O modules according to this disclosure. As shown in FIG. **4**, a primary I/O module with one or more programmable devices is operated at step **402**. This could include, for example, operating the primary I/O module **108** with one or more programmable devices **202***a*-**202***n*. The programmable device(s) **202***a*-**202***n* can be used to facilitate communications over one or more I/O channels. One or more configurations of the one or more programmable devices are stored at step **404**. This could include, for example, the control unit **206** in the primary I/O module **108** storing a data record for each I/O channel in the memory **204**, where the data record identifies the configuration of the programmable device associated with that I/O channel. Information associated with each I/O channel of the primary I/O module is stored in a configuration database at step **406**. This could include, for example, the control unit **206** storing information defining each I/O channel supported by the primary I/O module **108** in the memory **204**.

A fault associated with the primary I/O module is detected at step **408**. This could include, for example, the fault detection circuit **112** detecting a fault with the primary I/O module **108**. The fault could also be detected by any other suitable device, such as by the controller **106** or by the primary I/O module **108** itself.

The one or more stored configurations of the programmable device(s) in the primary I/O module are transmitted to a secondary I/O module at step **410**. This could include, for example, the primary I/O module **108** sending the database record(s) associated with the configuration(s) of the programmable device(s) **202***a*-**202***n* to the redundant I/O module **110**. The secondary I/O module uses the data to reconfigure its programmable device(s) at step **412**. This could include, for example, the control unit **206** in the redundant I/O module **110** receiving the data record for each I/O channel from the primary I/O module **108** and reconfiguring the programmable device **202***a*-**202***n* for that I/O channel based on the data record.

Measurement data for an I/O channel is captured at both the primary and secondary I/O modules at step **414**. This could include, for example, the control unit **206** or other component sampling the output of a counter implemented in a programmable device for a selected I/O channel. Any other suitable data could also be sampled. The sampling could occur upon a "gap has occurred" event in order to help synchronize the sampling, although other sampling synchronization techniques could be used. Channel data for the I/O channel is sent from the primary I/O module to the secondary I/O module at step **416**. The channel data can include the data from the configuration database, as well as the value sampled at the primary I/O module **108**. The same I/O channel is updated in the secondary I/O module using the data from the primary I/O module at step **418**. This could include, for example, updating the counter in the same I/O channel of the redundant I/O module **110** using the counter value from the primary I/O module **108**.

A determination is made whether there are more channels to be synchronized at step **420**. If so, a new channel is selected, and the process returns to step **414**. Otherwise, the secondary I/O module has been synchronized with the primary I/O module, and the secondary I/O module can operate in a primary mode at step **422**. The primary I/O module **108** that experienced the fault can remain out of service until repaired or replaced, at which point the new I/O module could begin functioning as a primary or secondary I/O module.

Although FIG. **4** illustrates one example of a method **400** for synchronizing dynamic process data across redundant I/O modules, various changes may be made to FIG. **4**. For example, while shown as a series of steps, various steps in FIG. **4** could overlap, occur in parallel, occur in a different order, or occur any number of times. As a particular example, steps **402-406** and **410-420** could occur prior to a fault being detected so that the secondary I/O module is immediately ready to assume primary operation when a fault occurs.

In some embodiments, various functions described above are implemented or supported by a computer program that is formed from computer readable program code and that is embodied in a computer readable medium. The phrase "computer readable program code" includes any type of computer code, including source code, object code, and executable code. The phrase "computer readable medium" includes any type of medium capable of being accessed by a computer, such as read only memory (ROM), random access memory (RAM), a hard disk drive, a compact disc (CD), a digital video disc (DVD), or any other type of memory. A "non-transitory" computer readable medium excludes wired, wireless, optical, or other communication links that transport transitory electrical or other signals. A non-transitory computer readable medium includes media where data can be permanently stored and media where data can be stored and later overwritten, such as a rewritable optical disc or an erasable memory device.

It may be advantageous to set forth definitions of certain words and phrases used throughout this patent document. The terms "application" and "program" refer to one or more computer programs, software components, sets of instructions, procedures, functions, objects, classes, instances, related data, or a portion thereof adapted for implementation in a suitable computer code (including source code, object code, or executable code). The terms "transmit," "receive," and "communicate," as well as derivatives thereof, encompass both direct and indirect communication. The terms "include" and "comprise," as well as derivatives thereof, mean inclusion without limitation. The term "or" is inclusive, meaning and/or. The phrase "associated with," as well as derivatives thereof, may mean to include, be included within, interconnect with, contain, be contained within, connect to or with, couple to or with, be communicable with, cooperate with, interleave, juxtapose, be proximate to, be bound to or with, have, have a property of, have a relationship to or with, or the like. The phrase "at least one of," when used with a list of items, means that different combinations of one or more of the listed items may be used, and only one item in the list may be needed. For example, "at least one of: A, B, and C" includes any of the following combinations: A, B, C, A and B, A and C, B and C, and A and B and C.

While this disclosure has described certain embodiments and generally associated methods, alterations and permutations of these embodiments and methods will be apparent to those skilled in the art. Accordingly, the above description of example embodiments does not define or constrain this disclosure. Other changes, substitutions, and alterations are also possible without departing from the spirit and scope of this disclosure, as defined by the following claims.

What is claimed is:

1. A method comprising:

receiving first data at a first input/output (I/O) module from a second I/O module, the first data defining a programmable device configuration;

configuring a programmable device in the first I/O module based on the first data, the programmable device associated with a first I/O channel of the first I/O module, wherein the programmable device implements a counter configured to count pulses in an input signal and output a first counter value;

receiving second data at the first I/O module from the second I/O module, the second data associated with a second I/O channel of the second I/O module, the second data comprising a second counter value associated with the second I/O channel; and

synchronizing the first I/O channel with the second I/O channel based on the second data, wherein the synchronizing comprises updating the counter based on the second counter value.

2. The method of claim **1**, further comprising:

sampling the first counter value at the first I/O module at substantially a same time that the second counter value is sampled at the second I/O module.

3. A method comprising:

receiving first data at a first input/output (I/O) module from a second I/O module, the first data defining a programmable device configuration;

configuring a programmable device in the first I/O module based on the first data, the programmable device associated with a first I/O channel of the first I/O module;

receiving second data at the first I/O module from the second I/O module, the second data associated with a second I/O channel of the second I/O module; and

synchronizing the first I/O channel with the second I/O channel based on the second data;

wherein the first I/O module comprises multiple programmable devices supporting multiple first I/O channels; and

wherein different ones of the programmable devices are configured based on different information contained in the first data.

4. The method of claim 3, further comprising:

receiving at the first I/O module multiple sets of second data, each set of second data associated with one of multiple second I/O channels of the second I/O module; and

synchronizing each first I/O channel with one of the second I/O channels based on one of the sets of second data.

5. The method of claim 4, wherein the first data is received and the programmable devices are configured before the sets of second data are received.

6. The method of claim 1, further comprising:

detecting a fault associated with the second I/O module.

7. A method comprising:

receiving first data at a first input/output (I/O) module from a second I/O module, the first data defining a programmable device configuration;

configuring a programmable device in the first I/O module based on the first data, the programmable device associated with a first I/O channel of the first I/O module;

receiving second data at the first I/O module from the second I/O module, the second data associated with a second I/O channel of the second I/O module;

synchronizing the first I/O channel with the second I/O channel based on the second data; and

detecting a fault associated with the second I/O module;

wherein the second I/O module operates as a primary I/O module and the first I/O module operates as a backup I/O module prior to the fault; and

wherein the first I/O module operates as the primary I/O module after the receipt of the first and second data, the configuration of the programmable device, and the synchronization of the first and second I/O channels.

8. An apparatus comprising a first input/output (I/O) module, the first I/O module comprising:

a programmable device associated with a first I/O channel, the programmable device configured to implement a counter, the counter configured to count pulses in an input signal and output a first counter value; and

a control unit configured to:

receive first data from a second I/O module, the first data defining a programmable device configuration;

configure the programmable device based on the first data;

receive second data from the second I/O module, the second data associated with a second I/O channel of the second I/O module, the second data comprising a second counter value associated with the second I/O channel; and

synchronize the first I/O channel with the second I/O channel based on the second data, wherein the control unit is configured to update the counter based on the second counter value.

9. The apparatus of claim 8, wherein the control unit is further configured to sample the first counter value at the first I/O module at substantially a same time that the second counter value is sampled at the second I/O module.

10. An apparatus comprising a first input/output (I/O) module, the first I/O module comprising:

a programmable device associated with a first I/O channel; and

a control unit configured to:

receive first data from a second I/O module, the first data defining a programmable device configuration;

configure the programmable device based on the first data;

receive second data from the second I/O module, the second data associated with a second I/O channel of the second I/O module; and

synchronize the first I/O channel with the second I/O channel based on the second data;

wherein the first I/O module comprises multiple programmable devices configured to support multiple first I/O channels; and

wherein the control unit is configured to configure different ones of the programmable devices based on different information contained in the first data.

11. The apparatus of claim 10, wherein the control unit is configured to:

receive multiple sets of second data, each set of second data associated with one of multiple second I/O channels of the second I/O module; and

synchronize each first I/O channel with one of the second I/O channels based on one of the sets of second data.

12. The apparatus of claim 11, wherein the control unit is configured to receive the first data and configure the programmable devices before receiving the sets of second data.

13. An apparatus comprising a first input/output (I/O) module, the first I/O module comprising:

a programmable device associated with a first I/O channel; and

a control unit configured to:

receive first data from a second I/O module, the first data defining a programmable device configuration;

configure the programmable device based on the first data;

receive second data from the second I/O module, the second data associated with a second I/O channel of the second I/O module; and

synchronize the first I/O channel with the second I/O channel based on the second data;

wherein the first I/O module is configured to operate as a backup I/O module prior to a fault with the second I/O module; and

wherein the first I/O module is configured to operate as a primary I/O module after the fault with the second I/O module.

14. A method comprising:

storing first data defining a configuration of a programmable device in a first input/output (I/O) module, the programmable device associated with a first I/O channel, wherein the programmable device implements a first counter configured to count pulses in an input signal and output a first counter value;

sampling the first counter value at the first I/O module at substantially a same time that a second counter value is sampled at a second I/O module;

storing second data associated with the first I/O channel, wherein the second data comprises the first counter value; and

during a synchronization process, transmitting the first and second data to the second I/O module.

15. A method comprising:

storing first data defining a configuration of a programmable device in a first input/output (I/O) module, the programmable device associated with a first I/O channel;

storing second data associated with the first I/O channel; and

during a synchronization process, transmitting the first and second data to a second I/O module;

wherein the first I/O module comprises multiple programmable devices supporting multiple first I/O channels; and

wherein the first data comprises different records associated with different ones of the programmable devices.

16. The method of claim 15, further comprising:

transmitting to the second I/O module multiple sets of second data, each set of second data associated with one of the first I/O channels.

17. A method comprising:

storing first data defining a configuration of a programmable device in a first input/output (I/O) module, the programmable device associated with a first I/O channel;

storing second data associated with the first I/O channel; and

during a synchronization process, transmitting the first and second data to a second I/O module;

wherein the first I/O module operates as a primary I/O module prior to a fault with the first I/O module; and

wherein the first I/O module transmits the first and second data to the second I/O module to enable the second I/O module to operate as the primary I/O module after the fault with the first I/O module.

18. The apparatus of claim 8, wherein:

the first I/O module comprises multiple programmable devices configured to support multiple first I/O channels; and

the control unit is configured to configure different ones of the programmable devices based on different information contained in the first data.

19. The apparatus of claim 8, wherein:

the first I/O module is configured to operate as a backup I/O module prior to a fault with the second I/O module; and

the first I/O module is configured to operate as a primary I/O module after the fault with the second I/O module.

20. The method of claim 17, wherein:

the programmable device implements a counter configured to count pulses in an input signal and output a first counter value;

the second data comprises the first counter value; and

the method further comprises sampling the first counter value at the first I/O module at substantially a same time that a second counter value is sampled at the second I/O module.

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